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ABSTRACT

Telewriting, televidec, and facsimile systems are new forms of teleconferencing which can transmit a variety of graphic and pictorial information on voice-grade telephone lines. All of the equipment employs solid-state circuitry to enhance performance and to exploit the limitations of a narrowband channel. Telewriters range from simple electro-mechanical pens through complex computer graphics systems. All forms generate graphic or written information. Slow scan televideo systems, which add the capacity to present pictorial information, transmit the picture over regular telephone lines or FM radio channels for display on a television monitor. The facsimile system, which can transmit documents over long distances within a few minutes, requires a transmitter and a receiver (or two transceivers) to convert the printed document into electrical signals to be sent over telephone lines. Such advancements in electronic technology as miniaturization of integrated circuitry for processors, dense memory chips capable of greater bit-packing, charge-coupled devices to increase storage capacity, and fast multiplier chips for more complex signal operations are chiefly responsible for improvements in these systems. As data compression becomes feasible, the total number of bits transmitted can be reduced to improve the image quality over a voice-grade telephone line. Tables and graphs are included. (BK)

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VISUAL SYSTEMS FOR TELECONFERENCING: TELEWRITING, TELEVIDEO, AND FACSIMILE

by

Christine Olgren

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VISUAL SYSTEMS FOR TELECONFERENCING: TELEWRITING, TELEVIDEO, AND FACSIMILE

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Introduction

Teleconferencing is people communicating with people. In education, business, industry, health, and a host of other fields, telephone networks link individuals in many geographic locations. Communication, however, sometimes requires both audio and visual elements. Although teleconferencing has proven to be an effective medium for verbal interaction, it has been limited in its capacity to provide visual information.

New telewriting, televideo, and facsimile systems have recently been introduced that are reshaping our conception of the telephone. Often equated with only audio communication, the telephone is now becoming an important visual tool capable of transmitting a variety of graphic and pictorial information, from free-hand drawings and computer graphics to pictures and paper copies. This increased visual capability greatly extends the role of teleconferencing in meeting informational needs. In education, for example, many types of visual illustrations can supplement audio instruction. Business teleconferences can include charts and pictures to facilitate decisions. Industries may exchange written information, make graphic presentations, or construct computer drawn diagrams. Remote diagnoses are possible in medicine, where doctors simultaneously view x-rays and discuss patient symptoms.

Telewriting, televideo, and facsimile are not new concepts. The first telewriter was marketed nearly 15 years ago. A prototype televideo system was developed in the late 1950's, and facsimile became feasible in the mid-1960's when AT&T opened its lines for data transmission. What is new about these systems is their increased performance and versatility. In these respects, they bear little resemblance to their predecessors. Most of this progress is directly attributable to electronic-digital technology. Its application has not only improved existing products like electro-mechanical pens, slow scan televideo, and fascimile. It has also made other devices possible--the Electronic Blackboard, graphics tablets, light pen-video writers, and computer graphics systems.

The development of these visual systems is primarily the result of a concentrated effort to more fully exploit the informational capacity of the telephone and other narrowband channels. This effort has been fueled by three factors:

- The increasing need for organizations and individuals to exchange many kinds of information quickly over long distances.
- Narrowband media, such as the telephone and SCA-FM radio, make more efficient use of available communications channels.
- The telephone is widely available, interconnecting almost every home and business in the nation.

Telecommunications is a mushrooming industry, especially since the advent of satellites; and communications channels must be carefully allotted in order to accommodate all of the users who wish to transmit audio and visual information, alphanumeric copy, and computer data (Gundlach, 1976; "Telecom Changes," 1977). While broadcast channels transmit many kinds of information, including animated audio, they require wide bandwidth and cannot be made available to everyone. Coaxial cable and microwave channels also have wideband capacity, but their installation is expensive and they serve limited geographical areas. The telephone and other narrowband channels are therefore unique in their ability to efficiently and economically transmit information to people in almost any location.

Approach of This Paper

This paper reviews telewriting, televideo, and facsimile systems that can be used to transmit visual information over a narrowband telecommunications channel, particularly voice-grade telephone lines. The general operation of each system is described, and a number of products in that category are summarized. The products listed are only examples of those available on the commercial market. The electronics industry is very large, and new products are continuously being introduced. In addition, many firms develop systems specifically to meet a customer's needs; and other companies sell only the memory chips, graphic boards, circuitry, and other components that are the basic building blocks of a videographics system.

The systems are compared according to key evaluational considerations, but no attempt is made to recommend one type of system or product over another. As will be seen, there are often necessary compromises especially between cost and performance, and a "best system" ultimately depends on the needs of the user.

All of the equipment reviewed employs solid-state circuitry in varying degrees to enhance performance and exploit the limitations of a narrowband channel. Because of the importance of electronic technology in developing improved visual systems, some recent advancements in this field are discussed.

Data compression techniques are the subject of much research, and they may make it possible to transmit higher quality images in less time than is currently possible. Some of these techniques are summarized at the end of the paper.

Before describing each system in more detail, it may be beneficial to provide some background information. This includes an overview of the types of information these systems can transmit, the limitations

of a narrowband channel, and some important considerations in evaluating any of the visual systems.

Overview of the Visual Systems

Telewriters, televideo and facsimile are all methods of transmitting visual information. They differ, however, in the kinds of material that can be produced. These differences are summarized in Table 1.

Telewriters are capable of generating hand-drawn graphics--line drawings, simple diagrams, words, equations. The graphic information is produced by writing on an electronic surface with a special pen. As the writing and drawing is presented, it is instantly transmitted to remote locations and usually shown on a TV monitor. Telewriting systems include electro-mechanical pens, electronic blackboards, light pen-video writers, and graphic tablets. These devices can be applied to a variety of informational needs. Electro-mechanical pens are widely used in business,

TABLE 1

VISUAL CAPABILITIES OF TELEWRITING, TELEVIDEO AND FASCIMILE SYSTEMS

Capability	Examples	Device
Hand-drawn graphics	Writing Drawings Outlines Equations Diagrams Graphs	Telewriters Electro-mechanical pens Electronic blackboard Light pen-video writers Graphics tablets
Instant transmission Shown on monitors or permanent paper and acetate copies Stored on audio tape		
Hand-drawn graphics and computer-drawn graphics	Free-hand drawings Traced diagrams Computer drawn symbols diagrams, graphics, schematics, charts Alphanumerics Graphics functions (zoom, reduce, lable)	Computer graphics
Instant or delayed transmission Shown on monitors Stored on tape, discs or in memory Reproduced on printers and plotters		
Graphics and pictures	Hand-drawn graphics Prepared graphics Writing Monochrome pictures Color pictures	Slow scan televideo
Delayed transmission Shown on monitors Stored or audio tape Reproduced on paper		
Paper reproductions	Typewritten pages Documents Prepared graphics Pictures	Facsimile
Delayed transmission Permanent paper copies		

industry, sales, banking, insurance, transportation, and government for both multi-point and point-to-point communications. In education, they have been employed to teach home-bound youth and distant adult learners. The Electronic Blackboard, graphic tablets, and light pens are relatively new, but they are primarily geared toward education or business and industry. In most cases, both audio and graphic information can be recorded on regular audio tape for playback at a later time.

Computer graphics systems can be used for hand-drawn information, but they are more specifically designed to produce symbols, diagrams and other graphics automatically drawn by a computer. The information may be transmitted to remote locations instantly or during a number of seconds, depending on the amount of detail. The graphics are shown on a TV monitor that is a part of a video display terminal. Although these systems can be used in many different ways, their graphics capability has made them especially attractive to industry, business, and scientific research, where they perform many design and drafting operations. They are used, for example, to construct parts drawings, logic diagrams, schematics, architectural designs, and maps. In some cases, a computer graphics system is interfaced to a host computer to provide a sophisticated data processing and production management system. The graphics information may be stored on tapes, magnetic discs or in computer memory; printers and plotters reproduce the drawings on paper.

Televideo systems transmit not only graphics but also pictures--in short, anything that can be captured by a video camera. The picture is transmitted during a number of seconds and shown as a still, or "frozen" image on TV monitors at remote sites. These systems, usually referred to as slow scan televideo, have primarily been used for security and surveillance, signature verifications, and other banking and industrial functions. However, because of their greatly improved performance, they are increasingly being used in video teleconferencing in education, business, health and other areas. Audio and visual information can be stored on regular audio tape, or a video frame-grabber

can be used to reproduce the image on paper.

Facsimile, like any paper-copying equipment, reproduces information on paper. However, there is one important difference--the copies of the original document are made at distant locations. Facsimile equipment reproduces many kinds of information--typewritten pages, graphics, pictures. The transmission time is delayed, typically ranging from two to six minutes, although sub-minute machines are now available. Facsimile machines are widely used in business and industry.

The creative use of any of the systems can provide a variety of visual information. The unit may be quite simple and inexpensive, such as an electro-mechanical pen, and yet transmit many kinds of hand-drawn graphics. It may also be highly sophisticated and combine units for even greater versatility. For example, a graphics tablet or video writer could be interfaced to a slow scan televideo system to transmit instant graphics, still pictures, or graphics superimposed over a background picture. The design could also include the ability to recall a previous frame of information or to alternately switch between a picture and graphics. With imagination (and the technical ability to interface the equipment properly), a system could be designed to meet almost any visual need.

Almost all of these devices are compatible with both regular dial-up telephone lines and dedicated teleconferencing networks, using a standard RS-232-C interface. The exceptions are those systems that transmit high amounts of information, such as a color slow scan televideo, which requires a special modem, and highly sophisticated computer graphics models which operate most effectively on data-grade telephone lines. Some facsimile machines are limited to point-to-point transmission.

With all of these systems, audio and visual information can be transmitted simultaneously on a four-wire network. However, because the graphic information usually takes up the entire telephone bandwidth, voice and graphics must be transmitted sequentially, or alternately, on a two-wire line.

The Problem of Limited Bandwidth

Although there have been rapid advancements in narrowband visual systems, none of the devices currently available have overcome the problems of limited bandwidth. This restriction has resulted in compromises in graphics capability, picture quality, and transmission time.

The bandwidth problem is due to the differences between audio and visual information. Both are analog signals, but their frequencies differ. (Frequency is measured in cycles per second and expressed as hertz.) A telephone channel is designed to transmit only the frequencies needed to make speech intelligible. This frequency range is from 300 to 3400 hertz (Hz). The telephone thus has a narrow bandwidth of 3100 Hz, or 3.1 kHz. FM radio, which has a bandwidth of 15 kHz, is also a narrowband channel. Visual signals, however, have a much wider range of frequencies. Broadcast TV or coaxial cable have a bandwidth of about 3.5 megahertz (MHz). One wideband channel is thus roughly equivalent to 1000 voice-grade telephone lines. On a wide band channel, a full video picture containing over 2 million bits of information can be transmitted in 1/30 second. It would take approximately 10 minutes to transmit the same amount of information over a voice-grade line, if the data were not manipulated or compressed in some way (Meyer, 1976).

How, then, is it possible to transmit visual information over a narrowband channel given the limited bandwidth? Most graphic material does not contain nearly as much information as a picture. In addition, it is either black or white and has no gray tones. Handwriting, simple diagrams, charts, and graphics can thus be transmitted in real-time. However, complex graphics and pictures contain more information than can be instantly transmitted. The information can be sent on a narrowband channel, but it takes longer to reach its destination. No one wants to wait 10 minutes to receive a picture over a telephone line. Given the narrow bandwidth, the transmission time can be decreased only by reducing the amount of information. Any picture contains redundant elements. This is especially true of animated video in which there is not really much change from frame to frame. If this redundancy is eliminated, the total amount of information is reduced and the picture can be transmitted faster. There is, however, only so much information that can be omitted before the image becomes distorted. For a telephone channel, this threshold is approached before the transmission time can be reduced to zero. For example, a slow scan televideo system eliminates animation, reduces the resolution and gray shading, but it still takes a minimum of 8 to 78 seconds to transmit the picture.

The bandwidth problem is the subject of much research, and many techniques are being developed to decrease transmission time without overly affecting the quality of the picture. These techniques for data or bandwidth compression use various mathematical transformations and coding methods to more efficiently eliminate redundant information. As new electronic devices become available to perform complex coding operations, data compression techniques will become increasingly more effective in reducing transmission time.

Evaluational Considerations

When evaluating any of the telewriting, televideo, or facsimile devices, there are a number of factors that should be considered in addition to the kinds of information each one can transmit.

1. Image quality
   a. Resolution
   b. Gray scale or color scale
2. Image storage capacity
3. Transmission time
4. Cost
5. Analog or digital signal processing
6. Compatibility with auxiliary units
7. Adaptability to future technical improvements
8. Ease of operation
9. Reliability

Of these considerations, image quality, storage capacity, transmission time, and cost are so closely interrelated that an improvement in one usually has adverse affects on the others. If the quality of the image is improved, the picture takes longer to transmit. A better quality picture also requires more storage capacity, increasing the cost of the system. Given marketing constraints, manufacturers often opt for a trade-off among these factors, primarily balancing cost and performance. This interrelationship may be better understood if each factor is described briefly.

Image Quality

The quality of the graphic or pictorial information generated by a visual system depends on its resolution and, in some cases, its gray or color scale.

Resolution refers to the total number of points, or individual elements, that comprise an image. The greater the number of elements, the higher the resolution. In some systems, such as electro-mechanical pens, graphics tablets, and facsimile, resolution is expressed as lines per inch. In systems that show the image on a TV monitor, resolution is usually expressed as the total number of lines and elements in the picture. This can be most easily visualized as a matrix of dots, as shown in Figure 1.

Figure 1. A Matrix of Picture Elements

Each dot represents picture information; therefore, the greater the number of dots, the better the image quality. For example, a standard TV picture has 480 horizontal lines composed of 640 elements. If the resolution is reduced to, say, 175 lines with 75 elements, there is much less information and the picture will be distorted and of poor quality.

In many images—most graphics and facsimile—there is no shading. An element is either black or white. Half-tone pictures require variations in gray levels. Thus the quality of the image also depends on the number of gray shades representing the original picture. In slow scan televideo, for example, the gray scale varies from 16 to 64 shades. A picture with 16 shades shows a contouring effect with noticeable jumps between gray tones. With 64 steps, the shading appears continuous, much like a photograph.

It is difficult to state what degree of resolution and gray shading is acceptable. It depends, of course, on the amount of detail in a picture. However, there is another factor which is the subject of many research studies—the degree to which humans do not perceive discontinuities but rather automatically supply the missing information (see Sharma and Netravali, 1977; Sakrison, 1977). In this sense, a TV picture with 300 lines may not appear to be that much different than one having 480 lines, especially when viewed at a distance.

Storage Capacity

Except for electro-mechanical pens and facsimile, all of the systems show the graphics and pictures on a TV monitor. The transmitted information, whether it is in analog or digital format, must therefore be converted to composite video signals. Most systems are designed to interface with a CRT (cathode ray tube) monitor that must be refreshed by a separate storage unit that holds the picture information. This information is rapidly and constantly scanned to produce the video signals.

The storage unit may be an analog storage tube, magnetic disc, or digital memory. Of these devices, a digital memory has distinct advantages. If a storage tube is used, the picture will decay in time. A digital memory constantly refreshes the picture as long as the power is on. It also has a long life and needs little or no maintenance, which is not usually the case with a magnetic disc. However, a digital memory may mean a lower quality picture.

The quality of the TV picture depends on the capacity of the storage unit. The monitor may be capable of displaying a high resolution picture with 480 x 640 elements, but the storage unit must be able to hold this amount of information. A digital memory often compromises on the quality of the image because of the great number of bits needed to represent a picture with this resolution. The primary factor is cost. A picture that is twice as good in quality requires at least four times as much memory storage at a proportional increase in cost.

Transmission Time

The time it takes to transmit a given amount of information depends on the capacity of the channel. Capacity refers to the rate at which information can be sent without error, and it is expressed as bits per second (bps). Although a channel's capacity is theoretically proportional to its bandwidth, it is usually less due to noise in the channel and other factors that cause errors. A regular telephone channel has a capacity to transmit 600 to 9600 bps, depending on the grade of the line, type of modem used, and signal-to-noise ratio. An ordinary line usually transmits 1200 to 2400 bps. Speeds of 4800 and 9600 bps are possible, but they require conditioned lines and special modems, which are more expensive.

Although the limitations of a narrowband channel often result in the delayed transmission of detailed graphics and pictures some devices transmit information faster than others. For example, slow scan televideo systems vary from 8.5 to 78 seconds or longer; facsimile ranges from 35 seconds to 6 minutes. A faster transmission time often means a lower quality picture because less information is transmitted. However, it may also be due to the application of more sophisticated technology. For example, one slow scan system uses a data compression technique called differential pulse code modulation to reduce transmission time while preserving picture quality. It requires a special modem, however; it is also the most expensive of the slow scan units.

Analog and Digital Signal Processing

Most of the telewriting and televideo systems convert the graphics and pictures, which originate as analog signals, into a digital format.

A digital format has two major advantages in transmitting visual information. First, digital signals can be manipulated more readily than analog signals. This consideration is especially important if different coding schemes or data compression techniques are to be used. Second, digital pulses are regenerated as new, clean pulses at each repeater station so they are not progressively distorted by channel noise. In analog transmission, the signals are amplified at each station and the noise, which is also amplified, accumulates during the transmission time (Martin, 1976).

The conversion process is performed by an electronic component appropriately called an analog-digital converter. In brief, the amplitudes of the analog signals are quantized into discrete set of values, as shown in Figure 2. These values are then sampled at specific points, and each sample is coded to produce a stream of binary (0,1) bits. The pulse stream which carries the video or graphic information, is modulated (usually

by frequency shift keying) to a carrier wave for transmission over the telephone line.

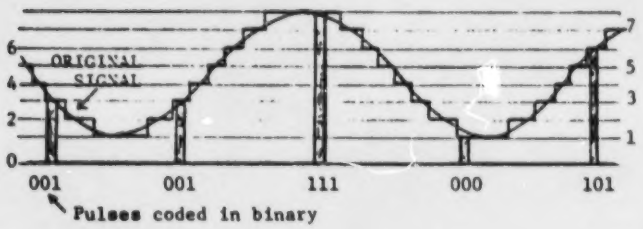

Figure 2. An Analog Signal in a Digital Format

For both narrowband and wideband channels, there is a strong trend toward coding the analog signals and transmitting them in a digital format. The telephone itself is beginning to convert to all-electronic networks of solid-state devices and computer control that are ushering in a new era of electronic mail, programmable telephones, and the digital transmission of voice, video, and data. (Erikson, 1975, 1977; Gundlach, 1975, 1977; Cole, 1975; Smith, 1977).

Telewriting Systems

Telewriting systems range from relatively simple electro-mechanical pens through complex computer graphics systems. Their common feature is the ability to generate graphic or written information. The material may be hand drawn using electronic pens, tablets, blackboards, and video writers; or it may be computer drawn with a computer graphics system. In most cases the information is instantly received at distant locations. The exception is detailed diagrams or schematics that may take a number of seconds to transmit.

Although telewriting systems differ in specific design and sophistication, they are based on the same principle: visual information can be transformed into voltage frequency signals by writing on a special conductive surface. Given a defined area, the exact location of each signal can be determined by measuring its vertical and horizontal position. For example, as one writes on the conductive surface of a graphic tablet with an electronic pen, voltage or frequency signals are generated. The positions of these signals are detected along x and y coordinates. Each letter or line is thus actually a series of points. After some processing, this information can be transmitted to a receiver that reproduces the writing. The receiver may be a mechanical pen that moves in response to the incoming signals, but in most cases the graphics are shown on a TV monitor.

Electro-Mechanical Pens

Electro-mechanical pens are probably the oldest of the telewriting systems. The first model, the Electrowriter made by Victor Comptometer Corporation, entered the market of telephone technologies in the early 1960's. Since then many improvements have been made in these devices to increase their performance. For example, solid-state integrated circuitry is now used for better fidelity and reliability. Their relatively low cost, direct hard-copy reproduction of writing and graphics, and ease of operation attracts many users.

Free-hand graphics and words are produced by writing on a paper-covered platen with a special pen that generates frequency signals. The signals are processed and transmitted simultaneously to any number of locations, where the information is reproduced on paper or acetate film by a mechanical pen on the receive unit. The paper is usually roll-fed and advanced automatically as one writes. Pre-printed forms are often used for routine communications such as sales requisitions and pharmaceutical prescriptions. The units are portable and can either be coupled to a standard telephone or wired for direct access to a teleconferencing network.

Examples of electro-mechanical pen devices are the Telenote/Telescreen system manufactured by Talos Systems, Inc., Telautograph Corporation's Telescriber and DY-II Telewriter, and the Electrowriter 2000 made by Infolink Corporation. Their characteristics are summarized in Table 2.

The Telenote transmitter consists of a writing area (4-1/4" x 6-1/2"), master printed circuit board, x-y plotter, and an electronic pen with no mechanical linkages. As one writes on the paper, the pen generates radio frequency signals that are detected by the plotter. The transmitter may also have an optional built-in conference speaker and microphone. The Telescreen receiver has a pen mechanism that etches the writing onto acetate film. The transparency is then projected onto a screen so it can be viewed easily by a number of people.

Telautograph's Telescriber and DY-II Telewriter models are basically the same in design and operation. The solid-state transmitter has a pen attached to a mechanical arm (servo-mechanism) that generates voltage frequency signals and positioning information. The paper-covered writing area is 3-1/2" x 5". The standard receive unit, like the transmitter has a mechanical pen with a ballpoint tip that reproduces the writing onto a 3-1/2" x 5" paper surface. The company also has a receiver with a thermal image pen for inkless reproductions. Telautograph will supply, on special order, a receiver that has an overhead projector so the information can be shown on a screen.

The Electrowriter 2000 made by Infolink operates in much the same manner as the Telautograph units. The Electrowriter is available as a transceiver, transmitter, or receiver. All have electro-mechanical pens and writing areas of 3-1/2" x 5", as shown in Figure 3. An optional device automatically prints the date and time that each message is received. Infolink is a subsidiary of Victor Comptometer Corporation.

Electronic Blackboard

The Electronic Blackboard designed by Bell Laboratories is another system that can be used to generate hand-drawn graphics and writing. What appears to be an ordinary blackboard is actually an electronic device that transmits written and drawn material over regular telephone lines. As one writes on the pressure-sensitive blackboard with a piece of chalk, the information is simultaneously shown on television monitors at remote locations.

TABLE 2

CHARACTERISTICS OF ELECTRO-MECHANICAL PENS

	Telewriter-Telescreen	Telescriber/DY-II Telewriter	Electrowriter 2000
Manufacturer	Talos, Systems, Inc.	Telautograph Corporation	Infolink Corporation
Transmitter	Paper platen Writing area 4-1/4"x6-3/4" Solid-state x-y plotter Electronic pen	Paper platen Writing area 3-1/2"x5" Solid-state Electro-mechanical pen	Paper platen Writing area 3-1/2"x5" Solid-state Electro-mechanical pen
Receiver	Acetate film Writing area 4-1/4"x6-3/4" Etching pen	Paper platen Writing area 3-1/2"x5" Electro-mechanical ink pen or thermal inkless pen	Paper platen Writing area 3-1/2"x5" Electro-Mechanical ink pen
Resolution	200 lines/inch		
Accuracy	1/64"		
Cost	$1475 - transmitter $1475 - receiver	$1095 - transmitter $1895 - transmitter/voice capacity $3095 - receiver $ 75 - direct wire interface	$1400 - transmitter $1425 - receiver

Figure 3. Electro-Mechanical Pen with Paper-Covered Platen

In addition to the blackboard itself, the basic system includes a control unit, a transmitter, and receiver (or two transceivers) to process the signals; 202-type modems, and a memory unit to store the information and refresh the video display. The system is compatible with almost any standard television monitor, although a 23-inch screen is recommended. The arrangement of these components is shown in Figure 4.

The blackboard is composed of two electrically conductive sheets separated by a small gap. When the flexible outer surface is touched with a piece of chalk, it contacts the inner sheet. The resulting voltages are detected and multiplexed to represent the x and y coordinates of the chalk's position. The voltage signals are sampled and digitally encoded by the transceiver and then transmitted over the telephone line at a rate of 1300 bits per second using frequency shift keying and a 202 modem. At the receive location, the signals are decoded and stored in a memory unit. The memory is scanned at the standard TV rate, and the resulting composite video signals are shown on the monitor. Because the memory is a scan-converter storage tube unit, it stores a frame of information for approximately 45 minutes. If a picture is continuously held on the monitor for a longer period of time, it begins to decay. The blackboard has a writing area measuring 42" x 56" and a resolution of 1000 x 1000 points, or about 20 points per inch. The resolution of the image shown on the monitor is about 300 x 300 points, which is comparable visually to a

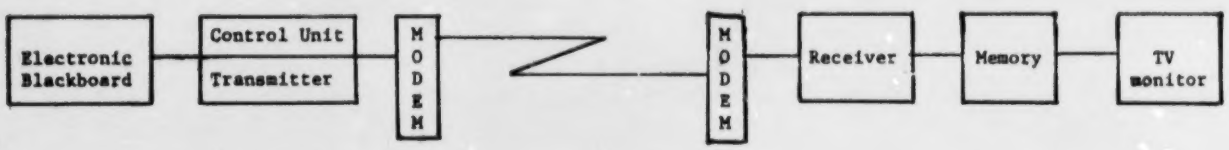

Figure 4. Basic Components of Electronic Blackboard System

standard television picture.

The control unit provides both erase and clear functions. A small part of the graphics shown on the monitor can be electrically erased by touching the blackboard at that particular point, or the entire display can be cleared.

An interactive graphics system is possible by installing transmit and receive units at each location. However, because a half-duplex channel is used, graphics cannot be transmitted in both directions simultaneously. Each location may interface up to three blackboards and three monitors to the transceiver. Voice communication is on a separate telephone line.

The hand-drawn graphics can be recorded on regular audio tape at the transmit site, or a video copier can be attached to the monitor for hard copy reproductions of the displayed images. Graphics and sound can both be recorded on a stereo recorder.

The Electronic Blackboard has so far been used only on an experimental basis. It has been tested at the University of Illinois, Urbana-Champaign, since 1974, where it has been installed at five locations to provide continuing education to engineers. Bell Laboratories is planning to file for tariffs and market the blackboard within the near future.

Light Pen-Video Writers

Hand drawn material can also be generated by writing directly onto a TV monitor with a light pen. In this case, the monitor may be thought of as an electronic grid that detects the pen's positions as it is moved across the screen. The signals representing the graphic information are then processed and transmitted to remote monitors.

An example of this type of device is the Video Writer manufactured by For-A Corporation of America. It is a self-contained unit consisting of a 12-inch monitor, semiconductor memory, and a light pen with a built-in microprocessor (see Figure 5). The TV picture area is divided electronically into more than 75,000 points, which change state when exposed to the signal emitted by the light pen. Thus, as the pen is moved across the screen, the points are interconnected to form letters and lines. The graphic information is stored in a semiconductor memory and can be distributed to other equipment connected into the system.

The Video Writer can perform a number of different functions that are controlled by the pen's microprocessor and a push-button operating panel. A straight line, for example, can be drawn automatically in either a vertical or horizontal direction by touching the pen to the line's starting point and depressing a button until the line is completed. Other functions allow partial or full erase of the graphics, up or down white-out to mask the picture, and selection of two line thicknesses.

The Video Writer is rather unique in that it is designed specifically to produce free-hand graphics for video systems. However, it is a peripheral unit and must be interfaced with other transmitting/receiving equipment. It is not clear if the graphics could be transmitted in real time on a narrowband channel, given the number of points to be coded. If this is the case, it might be feasible to implement a relatively simple data coding method to transmit only the changing points rather than an entire picture. This could make instantaneous transmission possible.

Because the Video Writer is compatible with nearly all television systems, it could be interfaced with a slow scan televideo unit. This combination of devices would provide hand-drawn graphics, pictures, and graphics superimposed over pictures. The white-out mode could be used to partially or completely mask over the background image while drawing with the pen.

The list price of the Video Writer, including the 12-inch monitor, is $5,386.

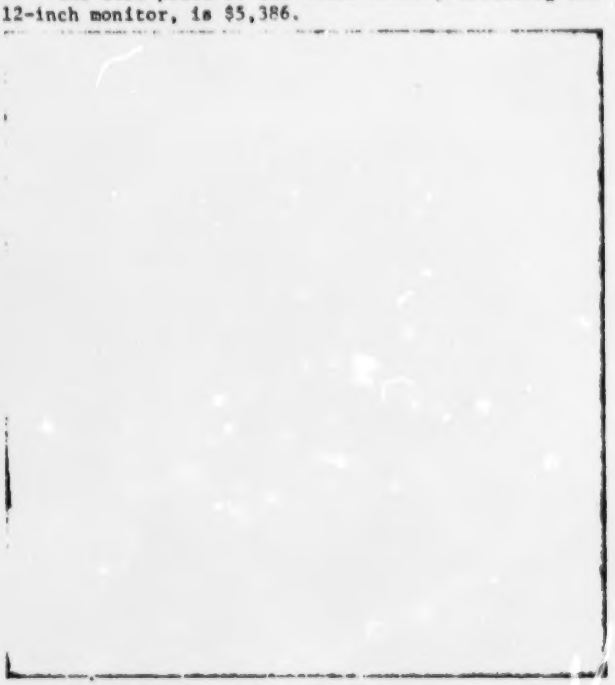

Figure 5. For-A Video Writer

A light pen is a rather simple device that contains a photosensitive cell and small-aperature lens. It can be used in a variety of ways--drawing, erasing, editing, entering data, determining coordinates. The functions it performs are controlled by a processor (microprocessor, minicomputer, or host computer) and software.

Light pens are most commonly used to determine coordinates on a CRT monitor. When the pen is placed on the screen, it responds to the brightness of the display and generates an electronic pulse that is transmitted to the computer. This interrupts the computer, which then determines the exact coordinates of the pen's position on the screen. Using the appropriate software, one can then enter data, erase or perform other functions at that point on the display. For example, the newspaper industry edits copy by touching a light pen to a misspelled word. The correct spelling is then entered on a keyboard. Industry uses light pens to assemble parts diagrams. When the pen is touched to a specific point, a sub-part called out of memory is automatically drawn at that location. Because a light pen responds to changing light, as in a CRT refresh display, it cannot be used with a storage-tube monitor.

Light pens alone can be purchased from a number of companies, including Information Control Corporation and Aydin Controls. However, they must be used in conjunction with a hardware-software package system appropriate to the user's needs. Many firms specialize in developing these systems, such as Digital Equipment Corporation and System Development Corporation.

Graphics Tablets

Graphics tablets are another type of televriting system that can be used for graphic information. Using a special conductive pen (or stylus), graphics are produced by writing on a piece of paper that is placed directly on the tablet's surface. The tablet is an electronic device that senses the pen's positions. The graphic information is digitized and transmitted to a remote TV monitor for display.

Some tablets are designed for hand-drawn graphics only. The Audiograph system, produced by Interand C Corporation, falls into this category. However, most tablets can be used in two ways: to produce hand-drawn graphics and computer graphics. Tablets made by Tektronix, Summagraphics, and Talos, for examples, can be used with a computer graphics system, where they perform other functions in addition to the free-hand writing and drawing. All of these tablets are summarized in Table 3.

TABLE 3

GRAPHICS TABLETS

Device	Transmitter	Receiver	Resolution (inches)	Accuracy	Cost
Audiografix System Interand Corp.	Oxide coated glass Conductive pen Solid-state memory	Digital memory (standard monitor)	.01	1%	$4000 (transmitter and Tablet)
4953 Tablet Tektronix, Inc.	11" x 11" surface Digitizing grid Conductive pen Control unit	Graphics display terminal with CRT monitor	.01	±0.03	$3195
4954 Tablet Tektronix, Inc.	40" x 30" surface Digitizing grid Conductive pen Control unit	Graphics display terminal with CRT monitor	.01	±0.10 over entire tablet	$5295
4956 Tablet Tektronix, Inc.	20" x 20" and 38" x 48" surface Digitizing grid Conductive pen Control unit	Graphics display terminal with CRT monitor	.005	±0.004	$4900 and $7300
Intelligent Digitizer Summagraphics	From 11" x 11" to 42" x 60" surface Self-calibrating grid Microprocessor Conductive pen Controller	Graphics display terminal with CRT monitor	.005	±0.004	$2400 to $6000
Cybergraphic Tablet Talos Systems, Inc.	From 11" x 11" to 44" x 60" surface Electronic closed loop servo system Conductive pen Control unit	Graphics display terminal with CRT monitor	.01 (.005 optional)	±0.01	$2500 to $6045

The Audiografix system is designed specifically to transmit free-hand or traced graphics over a voice-grade telephone line or radio subcarrier It consists of a graphics tablet, transceiver with a solid-state memory, and a conductive pen with a ball-point tip. As shown in Figure 6, a home monitor allows the user to watch the development of the graphic presentation. The tablet is actually a transparent piece of glass with a resistive oxide coating. It can be used in three different ways; the tablet can be placed directly over a standard TV monitor, it may be placed over a piece of paper for tracing graphic information, or a piece of paper can be placed over the tablet and one can write directly on the paper.

As one writes on the tablet (or paper) with the pen, voltage signals are generated and multiplexed for the x and y coordinates of the pen's position. The analog voltage signals are digitized and stored in the memory, which has a storage capacity of 1000 points in x direction and 512 points in y. The memory is then raster scanned to produce composite video signals to be shown on the home monitor. To display the graphics on TV monitors at remote locations, the information is transmitted as tone signals in an analog FM format.

The tablets made by Tektronix, Summagraphics, and Talos are similar in a number of ways. They can all be used to produce free-hand material, to digitize traced information, and to position graphics that are drawn by a computer.

For free-hand graphics only, these tablets would operate in much the same manner as the Audiographix system. One would simply write or draw on the tablet, and this information could be displayed on remote television monitors. The receiver would require memory storage capacity to refresh the video display and processing circuitry to convert the incoming digital pulses to composite video signals.

Figure 6. Interand's Audiografix System

When interfaced with a computer graphics system, these tablets perform additional digitizing and positioning functions. They can still be used for free-hand graphics, but they are also capable of digitizing detailed schematics and diagrams. In this case, prepared graphics are placed on the tablet and traced with the pen or a cursor. The information is digitized by the tablet and either shown on a TV monitor or entered into computer storage. As a positioning tool, the pen and tablet are used to determine the exact x-y locations for the insertion of computer drawn graphics--symbols, vectors, sub-diagrams. (Computer graphics systems are discussed in the next section.)

This type of graphics tablet typically contains parallel wires spaced one hundredth of an inch apart which run in both x and y directions to form a grid or matrix. As one writes on the tablet's surface, the pen and wires interact electronically to generate pulses representing the pen's position. The information is digitized as one writes. The spacing of the wires determines the tablet's resolution, which is usually expressed as a decimal number. Tablets with a resolution of .01 are capable of digitizing 100 lines per inch; those with a resolution of .005 reproduce 200 lines per inch. A typical digitizing rate is 100 coordinate pairs per second (Machover, 1977). This allows one to write at a speed of about 1 inch per second on a tablet with a .01 resolution, although speed also depends on the total bit output.

The surface area of the tablets ranges from 11" x 11" to 44" x 60". They are about 1/2" thick. The pens have either a ball-point tip or inkless stylus. For more exacting accuracy, push-button cursors can be purchased for $235 to $400.

The graphics tablets made by Tektronix, Inc., have electronic grids of iron-cobalt wires to digitize the graphics drawn on the tablet. Of the three Tektronix tablets, the 4953 is the simplest and least expensive. It converts graphics into a digital format in either a single-point or multiple-point entry mode using either the pen or an optional cursor ($235). The 4956 tablet, shown in Figure 7, digitizes graphics in four different modes: point--single-point; stream--continuous points; switch stream--continuous points only when the pen is down; and incremental--points updated only when the value changes. The 4953/54 tablets are compatible with Tektronix 4010 terminals, which cost $4450 and more, or the more sophisticated 4081 Interactive Graphics System. It costs $27,000. The 4956 tablet interfaces with the 4051 terminal, which has an 11-inch monitor and costs $7500. The graphic information can be stored on a peripheral disc or a digital cartridge tape recorder, and dry-process copies can be made on a Tektronix Hardcopy Unit that sells for $4295.

Summagraphic's Intelligent Digitizer has a built-in microprocessor that gives it greater flexibility. The microprocessor serves to implement such features as floating origin, incremental mode, binary to BCD conversion, output data formating as well as calculations of volumes, areas, linear displacements and perimeters. The tablet operates on a patented principle Summagraphics calls Magnetostrictive Ranging. It is compatible with terminals made by other companies, such as the 4010 Tektronix line.

The Cybergraphics tablet made by Talos uses a closed-loop electronic servo system to detect pen displacement. According to Talos, it is "...literally impossible to move the pen without detection." The tablet operates in five digitizing modes: single point conversion, continuous track, continuous run, remote from externally supplied signal, and incremental.

Figure 7. Teletronix 4956 Graphic Tablet

Computer Graphics Systems

Computer graphics sytems are capable of producing many types of graphics in addition to hand-drawn material. The design may be quite simple, generating lines, symbols, and simple diagrams; or it may be highly sophisticated and perform a variety of computer-controlled functions. The graphics capabilities of these systems may be summarized as follows:

1. Free-hand graphics: line drawings, graphs, writing produced on a graphics tablet or with a light pen.
2. Traced graphics: maps, schematics, structural and parts diagrams traced on and digitized by a graphics tablet.
3. Graphic symbols: programmed symbols stored in memory, selected from a menu or function keyboard and positioned by pen.
4. Computer-drawn graphics: software controlled graphics automatically drawn by a computer; position of drawing determined by pointing light pen or tablet pen at that point.
5. Alphanumerics: letters and numbers entered on a keyboard.
6. Special graphics functions: programmed graphic manipulations, such as three-dimensional rotation, zoom, magnify, reduce, label, as well as the plotting of bar charts or pie charts.
7. Hard-copy graphics: information reproduced by plotters and printers.

The kinds of information that can be generated on a computer graphics system depends on the hardware and software design. The basic blocking blocks of a system include: a graphics input device, processor, controller, and display unit or terminal. However, the arrangement of these units can be varied to provide different capabilities. Figure 8 illustrates two possible configurations.

The first configuration is a one-way system designed to transmit hand-drawn and computer-drawn graphics to a remote display unit that has a CRT monitor. A graphics tablet is used to produce free-hand drawings, writing or traced material. The control-processing unit includes a digital memory, logic circuitry, a programmable microprocessor, to provide additional graphics functions--symbols and lines, formatting, selective erase, conics and scrolling, upper and lower case letters, some mathematical operations. The information is transmitted to a remote display unit, and the graphics appearing on the CRT monitor may be automatically constructed by the computer, hand drawn, or a combination of both.

The second configuration has the same basic units as the first, but the design provides a much different graphics capability. In this arrangement, the display terminal and midicomputer interact as a sophisticated drafting system like that typically used in industry. A graphics tablet is again used to enter information, but here the graphics are more likely to be sub-part diagrams or schematics that are either shown directly on the monitor or sent to computer storage. A host midicomputer, which is time-shared by a number of customers, stores information in memory or on magnetic discs and tapes. The computer is programmed not only to draw lines and many types of symbols, but also to plot bar charts, rotate a diagram in three-dimensions, zoom, magnify, reduce, label, and perform other specialized functions. The display terminal is the drafting tool. It has a CRT monitor, keyboard, digital memory, and other circuitry. The operator sits at the terminal and begins a diagram by using the graphics tablet to designate the exact location where a symbol or sub-part is to be drawn. Operating the keyboard, the appropriate graphic information is called up and automatically placed at that point. The drawing may also be manipulated by rotating it for a three-dimensional view, magnifying one part while reducing another, or deleting sections. The development of the diagram is monitored on the CRT. After a series of graphic operations, the result may be a mechanical drawing of a tractor or an electrical wiring schematic, which can be reproduced by a plotter for permanent copy.

The examples in figure 8 represent arrangements that are virtually opposite in graphics capability. Because a computer graphics sytem is modular, it can be designed to meet many other types of informational needs. Perhaps the best way to illustrate the variety of systems possible is to discuss each of the units, or building blocks, in more detail. Machover (1977) and Lapidus (1976) discuss many of these considerations.

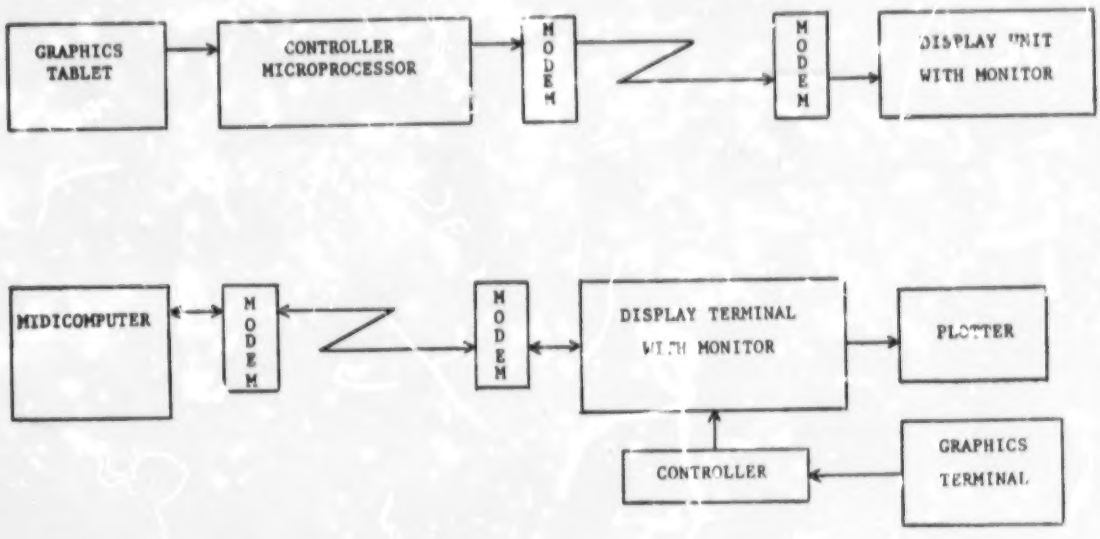

Figure 8. Two Possible Computer Graphics Systems

Graphics Processor: The graphics processor is the heart of the system. It is the computer hardware and software that provide the stored graphic symbols, interpret the operator's commands, and perform the appropriate graphics function (Coenen, 1976). It may be a microprocessor, a microcomputer, minicomputer, midicomputer, or a large main-frame computer. The graphic capability and cost of the system depend on the type of processor selected and its bit storage capacity. The larger processors have advantages in terms of greater programming flexibility, but their costs increase accordingly. Memory storage capacity can also vary widely, with 8000 bits usually a minimum amount. Many units have an add-on option so the memory can be expanded later. A microcomputer-based system can cost anywhere from $500 to $10,000. Whereas a midicomputer costs from $250,000 to $750,000, it can support a number of users in a time-shared mode.

As seen in the example configurations, the processor may be a part of the control-transmit unit or it may be a host computer. Another possibility is to design the processor into the display terminal, adding graphics functions that may or may not be supplemented by a host computer. A built-in processor is oftentimes a microprocessor. There is, however, a recent trend to increase the terminal's graphic capacity by incorporating a minicomputer or microcomputer that can be programmed to provide more sophisticated graphics.

A processing unit may also contain a graphics board, a hardware and software component that performs a number of routines. For example, a graphics board made by MiniTerm Associates interfaces to an Altair or IMSAI microcomputer. It has a programable read only memory that can generate 64 graphic characters. These are displayed in a 40 character by 20 line ASCII format with a resolution of 100 by 160 points. Some boards are also capable of producing color graphics or have higher resolutions. Vector Graphics, Inc. is another manufacturer of graphic boards. The average cost is from $200 to $300.

Graphics Input Device: A graphics input device performs two basic functions: it enters information and it positions that information in the desired location on the display. A graphics tablet is usually used for these two purposes; a light pen is another common positioning tool (see previous discussions of these two units). Information can also be entered from a keyboard, planimeter, or a microdensitometer. A keyboard is essentially used for alphanumeric data, such as text or labeling parts in diagrams. A planimeter, which has a mechanical arms, digitially generates point coordinates as it is moved over a flat surface. It is often used to measure areas on maps or engineering drawings. A microdensitometer is a type of film scanner that, like a TV camera, scans a picture to reproduce the matrix of picture elements. Graphics may also be positioned by a joystick or trackball, which define the x-y coordinates of a specific location.

Control Unit: The control unit links the input device and the processor. It is used to select the graphics and to instruct the processor to perform various functions. A graphics tablet has its own control unit and this may be sufficient for some purposes. Push-button cursors are also available to select symbols and position them on the display. In more complex systems, a control unit with a keyboard is used to instruct the processor.

Display Terminal: Display terminals vary widely in performance and design. It may be as simple as a CRT monitor and analog-to-digital converter; or it may contain a minicomputer, logic circuitry, and a keyboard to enter information and commands.

There are basically two types of CRT monitors. One requires constant refreshing and the other has its own storage capabilities. In many cases, the monitor is of the refresh type and must be updated 30 to 60 times per second by a buffer memory to maintain a constant picture. A refresh monitor has two primary advantages: it can be selectively rewritten without erasing the entire picture, and it can be used with a light pen. However, its resolution is limited by the total number of bits that can be stored in the memory. While a monitor having a storage tube with long-persistence phosphors may have a higher resolution, the total picture must be erased before a new image can be shown. One graphics system, the Tektronix 4081, differs in that it has a monitor that is both a refresh and storage type, offering the user a choice of how to best display the image.

Rather than a CRT monitor, a display terminal may have a plasma panel. Introduced on the market in the early 1970's, plasma panels are increasing in performance while decreasing in cost. The plasma display consists of two glass plates separated by a space filled with neon gas. When voltage is applied, bright orange neon dots are seen. Because the display is a direct representation of digital information, it does not require an analog-digital conversion like CRT. Panels are also twice as bright, have a wider viewing angle and less distortion (Turner, 1977; "Plasma Display Techniques," 1977). Plasma panels are capable of showing color, and pictures may be projected onto the back of the screen for front viewing.

The display's resolution, accuracy, and character repertoire are other factors that vary. One type of terminal is an alphanumeric display that has the conventional ASCII set plus standardized graphic characters. For example, a stroke generator can be used to produce 30 different line segments. These terminals typically have a resolution of 48 lines with 72 characters per line, limiting their application to simplified drawings and annotated information. However, their cost is less, generally starting at $2000.

Many display units/terminals operate in standard television formats. However, the resolution depends on the memory refresh capacity, scanning rate, and bandwidth. Depending on the unit, the resolution typically ranges from 200 x 200 elements to 480 x 640 points. Those units with higher resolutions are able to show more detailed diagrams, but they are also more expensive. High resolution monitors with 1024 x 1024 or even 4096 x 4096 addressable locations are also available for displays requiring exacting accuracy and dynamic images.

To illustrate a display terminal used for interactive graphics, the Tektronix 4010-1 model is shown in Figure 9. It is compatible with time-sharing systems, large mainframes, and minicomputers. Up to 1024 x 780 viewable points may be displayed on the storage CRT. It has a set of 63 printing characters and a generating speed of 1200 characters per second.

Communications Interface: Most computer graphics systems are designed to interface with narrowband communications channels, and the terminals usually have a standard RS-232-C communications interface. These systems typically transmit information at a rate of 2400 bits per second or less, and are thus compatible

Figure 9. An Interactive Computer Graphics Terminal

with a regular telephone channel. Speeds of 9600 bits per second or higher are possible, but special modems and data lines would be needed. The typical bit rate allows less complex graphics to be transmitted in real time, but detailed drawings and diagrams requiring a greater bit output would take longer to transmit, the time depending on the total number of bits needed to reproduce the information.

Some graphics systems are for local use only, or they require a wideband communications channel. In-house systems often have a high resolution terminal directly linked to a minicomputer. Systems requiring wideband channels are usually designed for animated and color videographics.

Products: Because computer graphics systems vary greatly in performance and cost, it is difficult to summarize products available on the market. Costs range from below one thousand to hundreds-of-thousands of dollars.

One source of computer graphics equipment is the hobby market. The Apple II microprocessor has color video graphics capability. It can display graphics in 15 colors with a resolution of 40 x 48 characters or four colors (black, white, violet, green) with a resolution of 230 x 192. The basic unit can be upgraded by adding a number of peripherals like disc storage modules. The Pet processor is a similar hobby system. Amateur radio operators are often adept at designing relatively inexpensive graphics terminals. Robertson (1973), for example, describes a unit built around an 8-bit microprocessor, 65,000 bits of memory storage, and a 12-inch monitor.

A typical interactive graphics system might range from $8,000 to $15,000. The cost also depends on the addition of peripherals, such as plotters, printers, cursors, hard copy units, digital cartridge recorders, and other devices. While some manufacturers offer a complete line of systems, individual components may be purchased from a number of companies, including just the software packages. Other firms specialize in designing systems specifically for the customer. Machover (1977) lists many of these companies according to the types of products they sell.

Many companies manufacture computer graphics systems that are primarily geared toward designing and drafting functions. These include:

Auto-trol Corporation	- AD/380 Design and Drafting System
Tektronix, Inc.	- Interactive Graphics Systems
Applicon, Inc.	- Graphics Systems
Bendix Communications Division	- Design and Drafting System
IBM-3250 Interactive Graphics Aydin Controls	- 5215 Limited Graphics System

Slightly different systems are made by Instronics, Ltd., Numonics Corporation, Optronics International, Inc., and Interand Corporation. Instronic's Gradicon Graphic system is a digital converter that employs a cursor that is moved over which digitizes prepared drawings, graphs, maps as it is moved over the surface. Numonics' Graphics Calculators are optical encoding systems that measure and digitize the areas of maps, blueprints, x-rays, as well as the lengths of river beds and highways, for example, Optronics' Digital Imaging Processors are high-speed microdensitometers, or rotating drums, that digitize, manipulate, enhance and reconstruct graphic/photographic imagery. Interand's Telestrator system is designed for wideband communications channels. It basically superimposes hand-drawn graphics and special graphic symbols over animated video pictures. Although it is designed for wideband communications channels and the transmission of animated pictures, it may be possible to modify this system for narrowband media by transmitting only the graphics in real time.

Slow Scan Televideo Systems

Slow scan televideo (SSTV) systems add another dimension to visual teleconferencing--the capacity to present pictorial information as well as graphics. Any image that can be captured by a video camera can be shown on a televideo system, including views of the instructor and classroom, outdoor scenes, handwritten and prepared graphics. The picture is transmitted over a regular telephone line or FM radio channel during a number of seconds and shown as a still image on a TV monitor. In most cases, the image forms gradually, starting at the top of the screen and moving down.

Slow scan televideo is, at this time, the only system capable of transmitting pictures over a voice-grade telephone line. As such, it has much potential in education, business, industry and other fields (Louv, 1977; Meyer, 1976; Meyer, 1977; Cohen and Meyer, 1975; Meyer, undated). The pictures are not animated, but movement may not be needed in many situations. Still images may actually be preferable, for they allow people to concentrate on the message by eliminating irrelevant motion. It may also be easier to remember a series of single pictures than continuously moving information.

The Picturephone developed by Bell Laboratories does transmit animated video. However, because it requires a special transmission channel of 1 MHZ, AT&T has virtually halted its installation and less than 1000 Picturephones are still in use. It displays 30 frames per second, which is similar to broadcast animation, and has a resolution of 251 lines with 211 picture elements per line. Bell Labs is working on a version of this unit that generates graphic data with a light pen and has a plasma panel rather than a monitor for display (Louv, 1977; Gundlach, 1975).

The basic units in an SSTV system are a video camera, transmitter, receiver (or transceiver), and TV monitors. Closed circuit television (CCTV) cameras and monitors are usually used. These units can be arranged in various combinations to provide one-way and interactive videographics between locations. Figure 10 illustrates two configurations. Multiple cameras can also feed one remote receiving site, or multiple cameras and monitors may be used at both the transmit and receive locations. In addition, auxiliary devices can be interfaced to the system. These units include video pointers, tape recorders, large-screen projectors, and frame-storers/grabbers for extra frame storage and hard copy reproductions of the images.

The core of the system is the transmitter and receiver or transceiver, which are basically scan converting devices. Scan conversion makes it possible to transmit a picture over a narrowband channel and view it on an ordinary TV monitor. In this process, the fast-scan (3.5 MHz) video signals are converted, or slowed down, to the allowable audio frequency of 3 kHz. This results in a longer transmission time that ranges from 8 to 78 seconds. The slow-scan signals are then reconverted at the receive site so the picture can be shown on a TV monitor.

The increased performance and flexibility of SSTV systems is primarily due to improvements in the scan converting units. Slow scan was developed in the late 1950's by Copthorn McDonald, but the transmitted image could not be reconverted into a conventional TV picture. Thus, a special monitor with a phosphor tube was used, and the image was of very poor quality (Louv, 1977). SSTV systems now use an analog storage tube, magnetic disc or digital memory to reconvert the signals and display the picture on a TV monitor. Of these three, a digital memory has distinct advantages. If an analog storage tube is used, the picture will decay in time. A digital memory constantly refreshes the picture as long as the power is on. A digital memory also has a long life and needs little or no maintenance, which is not the case with a magnetic disc (Steber, 1975; Ingram, 1976).

Digital signals can also be manipulated in more ways than analog, allowing, for example, different coding schemes and faster transmission times.

Selected SSTV Systems

Robot Research, Inc., Colorado Video, Inc. (CVI) and NEC-America, Inc. manufacture sophisticated SSTV systems that transmit pictures over a voice-grade telephone line. These systems are:

- Robot Phone Line Television Systems:
  - 520 transmitter
  - 510 receiver
  - 530 transceiver
- CVI Narrowband Video Systems:
  - 260B transmitter
  - 275A receiver
  - 275B receiver
- NEC Telephone Video Systems:
  - 754 transceiver
  - 751 transceiver

(monochrome and color)

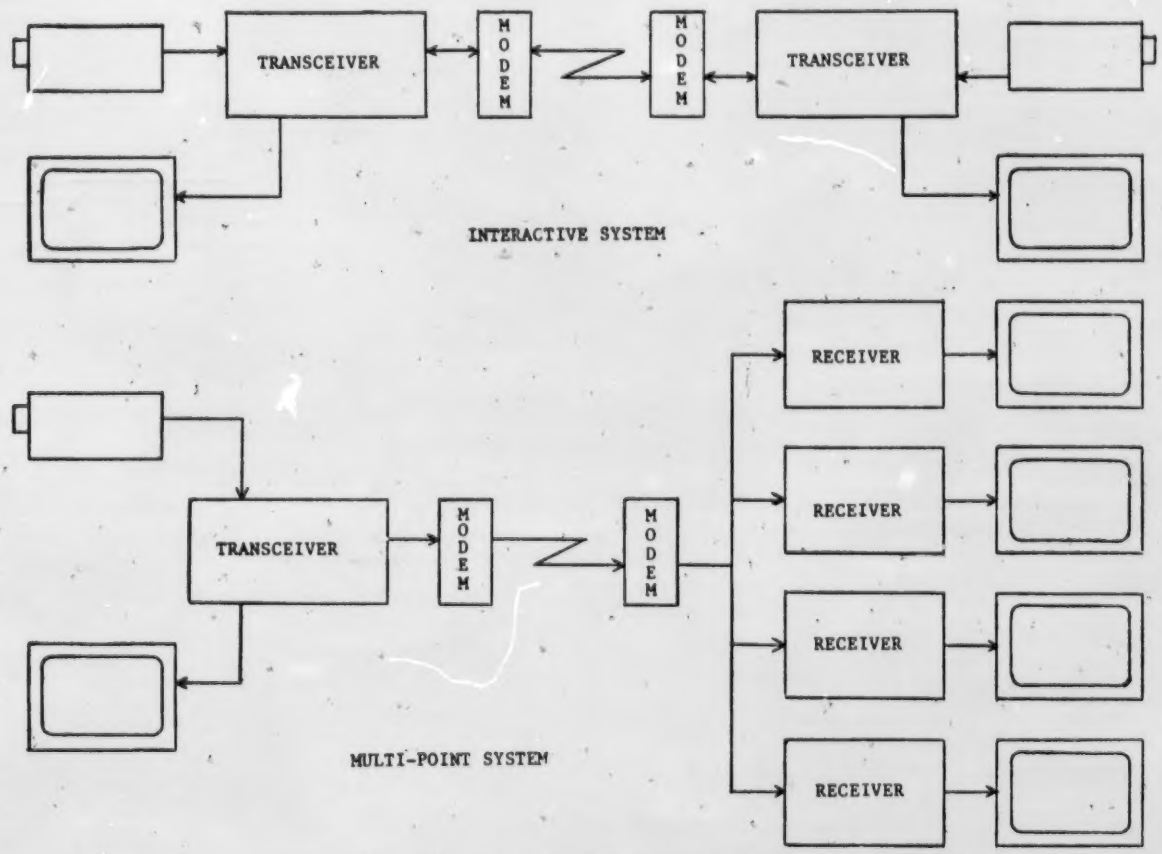

Figure 10. Basic Units in Televideo Systems

All of these units transmit monochrome pictures except for NEC's model 751, which transmits both monochrome and color. For color pictures, it requires a special modem. CVI also has a model 201A transmitter that operates on an 8 kHz bandwidth, such as an FM radio subcarrier. The transmission time is from 8 to 30 seconds, depending on the resolution and operating mode desired. The cost is $1950. It must be used with an 275-8 kHz receiver.

The Robot, CVI, and NEC systems have dynamic random access memories (RAM's) and integrated circuitry to store and process the picture information, and they all digitize the video signals. In addition, they share the following characteristics:

1. They accept standard monochrome, 525-line composite video input signals (1V peak-to-peak, 75 ohms). The NEC 751 unit accepts both monochrome and standard NTSC color signals.

2. The picture may originate from a video camera or a tape playback machine.

3. Using different camera lenses, the subject matter can range from handwriting to outdoor scenes.

4. They are compatible with a standard 525-line TV monitor (the NEC 751 can be used with an ordinary color TV set).

5. Signals are FM modulated for transmission (NEC 751 color unit uses pulse code modulation and predictive encoding to reduce the data.

6. Voice and pictures can be transmitted alternately on the same telephone line, and they can be transmitted simultaneously on a four-wire network.

7. Pictures can be transmitted automatically in a continuous mode or as single frames under manual control.

8. The TV picture is continuously refreshed and will not decay over time.

9. Video and audio signals can be recorded on conventional audio tape cartridges or cassettes for later playback (the NEC 751 color unit is compatible with any video tape recorder.

10. They can be interfaced with an auxiliary frame grabber/freezer as well as with a large-screen projector.

11. They cannot display a standard 300-word, 8-1/2" x 11" page, as this would require a very high resolution of 1000 lines.

Digital Scan Conversion: In addition to scan conversion, a digital memory stores the picture information and digitizes the signals. To perform these functions, it is composed of a core of memory cells, analog-to-digital converter, slow and fast scan clocks, sync circuits, digital-to-analog converter, and a series of input and output line buffers to clock the video in and out of the main memory. A typical arrangement of these components is shown in Figure 11.

The scan converter provides the appropriate circuitry to speed up the slow scan signals so they can be viewed on a conventional TV monitor, which displays 525 interlaced lines at a rate of between 15,000 to 16,000 lines per second. To do this, the incoming slow scan signals are demodulated and enter an analog-to-digital converter that changes the voltages into digitized binary equivalents. For example, in the Robot system, each line of slow scan video is sampled 256 times, resulting in 256 words that contain four bits of gray-scale information. The scan conversion takes place in the line buffers, which accept each line of digitized information and add it to the memory at the appropriate time. Timing is controlled by sync pulses that trigger the clocks. The memory operates at a fast-scan rate to continuously recirculate the picture information. This information is then converted from digital bits to analog video signals that are shown on the monitor (Steber, 1975; Ingram, 1976).

Operational Features: These units also have similar operating controls which allow some flexibility while maintaining simplicity. As shown in Table 4, pictures can be transmitted automatically or as single frames under manual control. A picture may also be held on the screen and viewed for any length of time. CVI's 260B transmitter has a more sophisticated remote control panel than does Robot's. With the CVI panel, one can select three separate video input sources, start or stop picture transmission, pause in the middle of a transmission for split-screen effects, and control an auxiliary frame freezer. Robot's 520 and 530 models have a test-memory-input switch that displays an internally generated gray scale. A switch on the 530 also allows one to view either live video or the slow scan image on the station monitor at the transmit location. The NEC 751 remote control panel has buttons that can be used to rewrite only the upper or lower half of the image.

Although SSTV systems are relatively simple to operate, some assistance or training would be needed, especially to transmit a picture. At the transmit end, one has to focus the video camera, tune the brightness and contrast levels, select continuous or single frame mode, and monitor the out-going video image. At the receive end, one only has to tune the picture quality and select the receive or hold mode.

Performance: The important differences among the CVI, NEC, and Robot systems are the picture quality, image storage capacity, transmission time, and cost. As was pointed out earlier, these factors are interrelated and result in trade-offs. This association can be seen by comparing the characteristics summarized in Table 5.

Picture Quality: The quality of the picture shown on the TV monitor depends on its resolution and gray (or color) scale. As discussed previously, each line of resolution is composed of a number of "dots" or picture elements (pixels). For a monochrome picture, each pixel is assigned a brightness value ranging along a gray scale from black to white. The more steps or levels in the gray scale, the more continuous is the shading effect. The total picture content is the algebraic product of the pixels and gray levels; the greater the picture content, the better its quality.

The Robot transmitter samples the video input signals and reduces the picture to a frame of information with 128 lines with 128 elements for a total of 16,384 pixles. Each pixel is assigned 1 of 16 gray levels. Thus the picture is represented by a total of

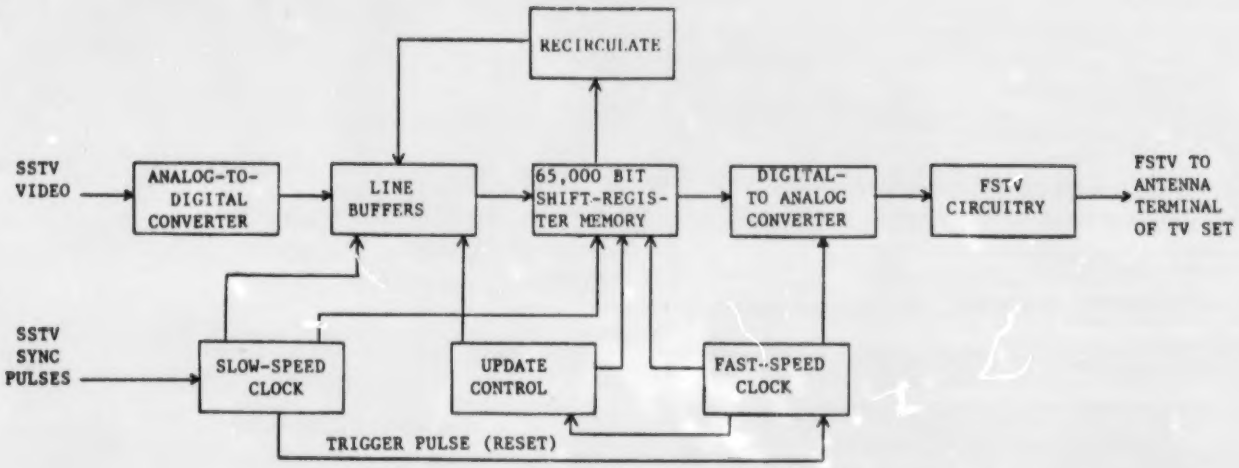

Figure 11. Typical Digital Scan Converter

65,536 bits of information (128 x 128 x 4, where 4 is the number of bits used to code 16 gray levels). This discrete array of picture elements gives the image a distinctly dotted appearance, called quantization. The 16-step gray scale also results in contouring of the individual gray shades. The quantization and contouring effects are especially noticeable when the picture is viewed at close range or on a larger monitor, for example, a 17-inch screen. Robot is developing a 256 x 256 resolution unit, but marketing plans are as yet indefinite. The Robot picture also has a square format, or 1:1 ratio. When shown on the TV monitor, the right and left sides of the screen are blanked.

The CVI 275B receiver produces an image with a resolution of 256 x 512 elements (131,072 pixels). Six bits are used to code each pixel as one of 64 gray levels, so the picture has a total of 786,432 bits of information. In comparison to Robot, the CVI picture contains more than 8 times the number of pixels and 12 times the total number of bits of information, resulting in much more picture detail. This minimizes the quantization and contouring effects, and the CVI picture is comparable to an ordinary TV image. The picture also has a 4:3 ratio.

NEC's units transmit one full picture field composed of 750,000 bits of information, on a resolution of about 262 x 340 pixels. The 754 monochrome image has 64 gray levels. The 751 model is unique, for it displays a picture in full NTSC labor.

Image Storage Capacity: The image storage capacity refers to the total amount of picture information that can be stored in the transmitter's and receiver's memory. A digital memory stores the resolution and gray scale values as bits of information in binary (0,1) form. The location of each pixel is stored as one bit; additional bits are needed for the gray shades.

The relationship between the quality of the picture and the storage capacity can be illustrated by using Robot's system as an example. The Robot picture has a resolution of 128 lines and 16 gray levels, which requires a memory storage capacity of 65,536 bits (excluding buffer memory). If the resolution is doubled from 128 to 256 lines, four times the amount of picture information has to be stored (the number of lines is roughly proportional to the square root of the number of pixels). If the gray scale is increased from 16 to 64 shades, two more bits per pixel are also required. Thus, by doubling the resolution and improving the gray scale, the memory storage requirements are increased six times, from 65,536 to 393,216 bits.

This increase in storage capacity yields a higher quality picture, but it also means a substantial increase in cost. This relationship is evident when the Robot and CVI systems are compared:

Receiver	Storage Capacity (bits)	Cost
Robot 510	65,536	$ 1,395
CVI 275A	393,216	9,000
CVI 275B	786,432	12,000

The difference in cost between the Robot 510 and CVI 275A compared to the relatively lower cost of the CVI 275B may reflect, in part, the pricing of memory chips--the cost per chip decreases after a certain number.

Transmission Time: Given the limitations of a narrowband channel, the transmission time is probably the most difficult problem in televideo systems. The best voice-grade telephone line carries 9600 bits per second, and an average line carries only 1200 or 2400 bits. How then can a complex video image be transmitted in a reasonable amount of time?

The most obvious solution is to reduce the quality of the picture. Robot samples the input video signals to decrease the picture content to about 65,000 bits. This information is transmitted in 8.5 seconds. Compared to Robot, the CVI systems have relatively slow transmission times of 39 and 78 seconds; however, they are transmitting more information and, consequently, a higher quality image. Excluding the cost factor, the difference between Robot and CVI system is essentially image quality vs transmission time.

NEC's 751 system, on the other hand, transmits 750,000 bits of information, representing one field of full NTSC color, in 75 seconds at a rate of 9600 bps. This relatively fast time is attributable to a coding scheme called differential pulse code modulation. It is used to reduce the number of bits needed to code the color values, resulting in a 2:1 compression ratio. A

TABLE 4

PHYSICAL SPECIFICATIONS OF SELECTED SSTV SYSTEMS

Transmitters	Dimensions (Approximate Inches)	Weight (Pounds)	Operating Controls		Modulated Carrier
Robot 520	12 x 11 x 7	12	Power: Off/on Video: brightness contrast Display Test memory input Audio level Frame grab: automatic, single step	Remote frame grab jack: automatic, single step	1.9 V p-p, 900 ohm 1500-2300 Hz, 1200 sync
CVI 260B	5 x 19 x 12	30?	Power off/on Video level Black level Scan: single/continuous	Remote: video source 1/2/3 Pause/scan Send Freeze Reset	1V peak-to-peak 600 ohms, 1500- 2300 Hz
Receivers					
Robot 510	12 x 11 x 7	12	Power off/on Receive/Hold Width (picture scale) Contrast, brightness	Remote: Receive/Hold	
CVI 275	10 x 19 x 15	30	Power off/on Receive/Hold	Indicators: AC power scan black level white level	
Transceivers					
Robot 530*	12 x 11 x 7	12	Power off/on contrast, brightness Modes: Receive Hold Transmit Camera Test Scan: Automatic Frame grab Single step		1.9 V p-p, 900 ohms 1500-2300 Hz
NEC TVS-754 (Mono)	17 x 17 x 15 (main frame) 17 x 17 x 7 (power supply)	55 44	Power off/on	Remote: Transmit Record Ready	-20 to 0 dBm, 600 ohms
NEC TVS-751 (Color)	17 x 17 x 15 (main frame) 17 x 17 x 7 (power supply)	55 44	Power on/off	Remote: Transmit Ready Receive Full Upper Lower Sequence One-Shot	Modem interface: + (8+2)V -

*The 530 is a version of Robot's Model 400, which is designed for ham radio operators. In the 530, some of the control flexibility has been eliminated to simplify operation.

TABLE 5

CHARACTERISTICS OF SELECTED SSTV SYSTEMS

	Storage Capacity	Picture Elements (V X H)	Gray Levels	Trans Time Per Frame (Seconds)	Cost
Transmitters					
Robot 520	Digital memory 4k dynamic RAM 65,536 bits	128 x 128	16	8.5	1,545
CVI 260B	Stores each line of 1536 or 3072 bits	256 x 256 256 x 512	64	39 78	3,000 3,000
Receivers					
Robot 510	Digital memory 4k dynamic RAM 65,536 bits	128 x 128	16	8.5	1,395
CVI 275A	Digital memory 4k dynamic RAM 393,216 bits	256 x 256	64	39	9,000
CVI 275B	Digital memory 4k dynamic RAM 786,432 bits	256 x 512	64	78	12,000
Transceivers					
Robot 530	Digital memory 4k dynamic RAM 65,536 bits	128 x 128	16	8.5	1,695
NEC TVS-754	Digital memory 4k dynamic RAM 750,000 bits	262 x 340*	64	30	18,000
NEC-TVS-751 (Color)	Digital memory 4k dynamic RAM 750,000 bits	262 x 550*	Full NTSC color	75 to 300**	19,000

*NEC units transmit one field of 750,000 bits of information. Robot and CVI units transmit frames of information (two interlaced fields equal one frame).

**Transmission time depends on grade of telephone line; worst case of 2400 bits/second requires 300 seconds; 4800 bits requires 150 seconds; best case of 9600 bits/second requires 75 seconds.

special modem must be used to transmit the data at 9600 bps over a telephone line.

Other Slow Scan Equipment: Other companies that manufacture slow scan equipment include:

Hughes Industrial Products
Princeton Electronics
Alden Electronics
Venus Scientific, Inc.
Javelin Electronics
Media Concepts, Inc.
Teltron, Inc.
Infoteknics, Inc.
Hitachi Sales Corporation of America
Westinghouse
Spatial Data Systems

Hughes and Princeton Electronics both manufacture storage-tube scan converters. The Hughes model 639 has a storage capacity equivalent to 750,000 bits. This information is transmitted in 100 seconds or stored for a minimum of 25 minutes. The cost is roughly twice that of the CVI or Robot transmitters.

Alden Electronics have frame grabbers that reproduce slow scan pictures onto electrosensitive recording paper (similar to facsimile). The units interface to a scan converter. The model 600 records a frame of video in 40 seconds on a paper copy that is about six inches wide. Alden also has an 11-inch recorder that can be used to reproduce images at remote locations. Although the recorder is compatible with other SSTV systems, such as CVI, Alden prefers to interface the unit to a Hughes scan converter and an Alden slow scan

modem. The picture is transmitted in 100 seconds, and the printout has a resolution of 65 lines per inch.

Venus Scientific has a basic system for ham radio operators. Its camera-transmitter transmits a picture with a resolution of 128 x 128 picture elements and six or seven gray levels in 8.5 seconds. Its receiver uses a phosphor storage tube. Venus is planning to market a unit next year that has a digital memory with a capacity of 16 gray levels.

Javelin Electronics and Media Concepts have simple scanning systems that are used for security purposes in banks and other institutions. Each of these systems consists of a video camera, frame freezer, and video tape recorder.

Teltron makes only the storage tubes that can be used in an SSTV system rather than a digital memory.

Infoteknics has a video display system called Teledisc. Information about this system was not available from the company. According to Meyer and Brown (1976), the Teledisc system uses magnetic discs to transmit a picture over the phone lines. One magnetic disc, rotating at 1800 rpm, stores a standard TV frame. The disc is then slowed to rotate once every 84 seconds, and the TV frame is transmitted to another machine that has a disc rotating at the same speed. After 84 seconds the speeds of both discs are increased and the picture is displayed.

The Hitachi MS-200 Frame Grabber is also a magnetic disc unit. It has a rotating speed of 3600 rpm. Each video field is stored on a separate track and multiplexed to generate a complete frame. It sells for less than $1000.

Westinghouse will apparently develop and build, on special order, a two-terminal SSTV system for about $80,000.

Spatial Data Systems manufactures the EyeCom Picture Digitizer and Display, which scans and digitizes pictures for computer processing. EyeCom is primarily an in-house system used for image enhancement. For example, the slow scan picture shown on the display terminal can be graphically analyzed or written titles and supplementary data can be overlaid on the image.

RCA previously manufactured an SSTV transceiver called Video Voice (see Cohen and Meyer, 1975; and Meyer, 1976 for discussions of this system). Video Voice units are no longer built or operationally supported by RCA, but surplus models can be purchased for about $2400. Video Voice transceivers have an image storage tube and transmit a picture with 480 x 512 or 480 x 256 pixels in 55 or 30 seconds, respectively.

Facsimile Systems

With a facsimile system, documents can be transmitted over long distances and reproduced at remote locations within a matter of minutes or seconds. The material may be typewritten text, diagrams, engineering drawings, business forms, computer printouts, illustrations--virtually anything that is shown on a piece of paper.

A facsimile system consists of two machines: A transmitter and a receiver (or two transceivers). The transmitter converts the printed information into electrical signals that can be sent over an ordinary telephone line. The conversion is done by a scanner, often an optical device, that rapidly scans the page line-by-line in either a horizontal or vertical direction. The resulting electrical signals are then modulated to a carrier wave for transmission. At the receive site, the signals are demodulated and the information is reproduced on paper. In some receivers, electrosensitive recording paper is placed on a high-speed rotating drum. Each revolution of the drum corresponds to a line of print. When the writing mechanism, which is simply a piece of fine wire, touches the paper, it passes electrical current through the paper to the metal drum to "burn" the information onto the page. To operate properly, the transmitter and receiver must be carefully synchronized. A series of sync pulses are therefore sent along with the signals that represent the printed information (Heiserman, 1971).

Facsimile, like other narrowband visual systems, has been greatly improved in the last few years, especially in performance and standardization. The business facsimile market opened up in the mid-1960's, but most of the equipment was special-purpose and not standardized. By the early 1970's, machines were available that could transmit a page of information in six or four minutes. Three-minute and two-minute models soon followed. With the application of microprocessors and solid-state electronics, facsimile equipment is changing rapidly. New sub-minute machines were introduced in 1977; and slower equipment has increased in performance, offering a variety of automated features. While there was previously little standardization on scanning, synchronization, and transmission procedures, most of the six- and four-minute units are now generally compatible. Groups such as the International Telegraph and Telephone Consultive Committee (CCITT) are working to standardize the high-speed machines for both domestic and international use (Krallinger, 1974; "Facsimile: 1978 Overview", 1977).

Facsimile was actually invented 130 years ago and patented by Scottish Inventor Alexander Bain as an "automatic electromechanical recording telegraph." When photoelectric scanning was introduced in the early 1900's, facsimile became a more feasible method of transmitting information, and the first network was set up in Germany. AT&T, RCA, and Western Union began experimenting with facsimile in the 1920's, and AT&T's Telephoto and RCA's international radiophoto systems were soon in operation. Newspapers were early users of facsimile. The Associated Press acquired AT&T's network and renamed it Wirephoto, and other newspapers soon developed their own picture transmission networks. Today facsimile is often used to exchange information in business and industry, especially in manufacturing, communications, printing and publishing, finance and banking, transportation, utilities, and retailing and wholesale. Using communications satellites and land lines, international facsimile networks also link people worldwide ("Facsimile: 1978 Overview," 1977).

Most facsimile machines can be acoustically coupled to any standard telephone to transmit information over ordinary voice-grade lines, or they may be hand-wired to a leased line. However, the increasing popularity of these systems has led to a number of specialized facsimile networks. South Pacific Communications offers a common carrier service called Speedfax that allows a customer to send a page of information from New York to Los Angeles, for example, at a cost of about 20¢. While it accommodates regular analog machines, its dial-up digital channels are capable of sending information at a rate of 9600 bps and are thus compatible with the new sub-minute digital equipment ("Facsimile: 1978 Overview," 1977). ITT Domestic Transmission Systems recently intro-

duced its new FAX-PAC service. As a nationwide packet-switched data communications network, it provides a common link between facsimile equipment that has previously been incompatible. It utilizes 10 major computer centers and 14 concentrator sites to convert the software protocols, codes, and speeds of facsimile machines, allowing most of the commonly used equipment to interact. The network also features a store-and-forward service--the customer can store the message at a network location and forward it later to compensate for time zone differences or take advantage of lower rates. Messages can also be sent simultaneously to different locations. FAX-PAC is the first of the telecommunications services to be offered in the COM/PAK network, which in the future will link not only facsimile machines but also teleprinters, video display terminals, and processors into a common interactive network. COM/PAK has been approved by the Federal Communications Commission.

Performance Considerations

There are a number of considerations to keep in mind when evaluating facsimile equipment. These include:

1. Resolution - number of reproducible lines per inch (lpi)
2. Transmission time
3. Multi-point or point-to-point transmission
4. Automatic or manual send and receive
5. Flat bed or drum scanning
6. Reproduction process
7. Purchase or lease (including maintenance)
8. Compatibility with other facsimile systems

Like the telegraphic and televideo systems, facsimile can transmit only so much information in a certain amount of time over a narrowband channel. The result is less-than-perfect resolution, and the copy will show some distortion. This can be seen in Figure 12, which illustrates facsimile copy with a vertical and horizontal resolution of 96 lpi sent long distance in six minutes. Although the information is readily intelligible, there is some fuzziness. Resolution also varies with transmission time. If this same material had been transmitted in four minutes, the vertical resolution would be decreased to 64 lpi. The resolution of facsimile machines ranges from 63 to 200 lpi; 96 lpi is common for a six-minute mode.

Figure 12. Example of Facsimile Copy

The transmission time is another variable factor. It ranges from six minutes to 20 seconds for a standard 8-1/2" x 11" page. Many machines have multiple transmission speeds, allowing the user to select the speed most applicable to a given document (a slower time permits a higher resolution). Documents that are smaller in size, such as 8" x 5", can be sent faster. To transmit a page in 20 to 35 seconds, the new high-speed machines operate at a rate of 9600 bps, which requires a special modem. These units also employ data compression techniques to reduce the total amount of information transmitted. In most cases, Huffman coding is used, a scheme that looks at each scan line, analyzes the amount of black and white information, and decides on the most efficient way to send it ("High-Speed Fax", 1977).

Most facsimile systems are designed to interact on a point-to-point basis, and a typical arrangement is to install a transceiver at both locations. However, some transmitters can serve a limited number of receivers in a multi-point network.

While many units offer automatic send and receive operations, some machines must be loaded and unloaded by hand. Both types have distinct advantages. A manual machine is relatively inexpensive and is often sufficient for low-volume use. Automated equipment provides greater operational flexibility and is more efficient in high-volume situations. The more sophisticated automated units have the following features:

--Unattended transmission (polling): The unit automatically answers a call, transmits the copy, and disconnects the telephone at the end of the message.

--Automatic Message Loader: Allows as many as 100 documents to be loaded without operator attendance. In some cases, the documents can vary in length from 3 inches to 200 feet, lengths can be intermixed, and the paper can be of different thicknesses.

--Continuous Roll Feed: Allows nearly 200 messages to be continuously received.

--System Assurance: Indicates that the message is properly loaded and is being received at the other end of the line. The system automatically shuts down if there is a telephone, equipment, or power failure.

A document may be reproduced either by flat bed scanning or by attaching it to a rotating drum or cylinder. Drum scanning is often used in lower-cost, manually operated units; automated machines employ flat-bed scanning, where the document is scanned electronically as it moves through the machine.

Copies are usually made on one of three types of paper: Electrolytic, electrosensitive, or electrostatic. There is only one machine on the market, the Xerox 200 telecopier, that reproduces the information on ordinary paper.

Facsimile equipment can either be purchased or leased, but 97% of all units are rented. Lease plans vary--monthly rates, yearly rates, flat rates, charge per transmission, and other arrangements are possible. Maintenance contracts also differ, and in some cases, one may choose an option-to-purchase plan, deducting a percent of the rental fee from the purchase cost.

Products

Facsimile equipment is manufactured by various companies, and most firms have a line of machines that differ in performance and price. The most prominent companies are Xerox, Graphic Sciences, 3M, and Qwip, which provide over 80 percent of all machines currently in use. Some of the facsimile manufacturers are:

Xerox Corporation
Graphic Sciences (Burroughs Corporation)
3M Company
Qwip Systems (Exxon Enterprises)
Steward-Warner Datafax Corporation
Rapidfax Corporation
Telautograph Corporation
Muirhead, Inc.
Alden Electronics
Infolink Corporation

TABLE 6.

CHARACTERISTICS OF SELECTED FACSIMILE SYSTEMS

Manual Systems

Device	Resolution (V/H)	Transmission Time (Minutes)	Features	Approx. Cost
Qwip 1200	64/96 96/96	4 6	Two speeds Rotating drum Electrosensitive copy	$1117 $28/month
Graphic Sciences DEX Broadcaster	88	3	Simultaneous Send to 10 locations Rotating drum Electrosensitive copy	$7207 $170/month
Graphic Sciences DEX I, 180, 280	88	3 6	Two speeds Rotating drum Electrosensitive copy	
Graphic Sciences DEX 700	62 88	2/4 3/6	Four speeds Rotating drum Electrosensitive copy	
Xerox 400-1 telecopier	64/96 96/96	4 6	Semi-automatic load/eject Electrosensitive copy	$1710 $50/month
3M 2346	64/96 96/96	2/4 3/6	Four speeds Semi-automatic load/eject Transmission interrupt Electrosensitive copy	$60/month

Two to Six Minute Automated Systems

Xerox 200 Telecopier	77/80 96/96 64/96 96/96	2 3 4 6	Four speeds Flat bed Automatic send/receive Document loader Roll-feed Ordinary bind copies	$8075 $235/month
Xerox 410 Telecopier	64/96 96/96	4 6	Two speeds Automatic send/receive 75-document loader Roll-feed Electroresistive copy	$2845 $93/month
Graphic Sciences 4000 Series	62 88 124 176	2/4 3/6 4/9 6/12	Multiple speeds Flat bed Automatic 100 document loader Electrosensitive copy Use with FAX 900 broadcaster to transmit to 25 locations	$6240 $159/month + $35-$95/ month for Broadcaster
Stewart-Warner Datafax	96	3 (Model 360) 4.5 (Model 240) 6 (Model 180) 9 (Model 150)	One speed Automatic send/receive 75 Document loader Roll feed System Assurance Electrolytic copy Flat bed	$60/month

Two to Six Minute Automated Systems
(Con't)

Device	Resolution (V/H)	Transmission Time (Minutes)	Features	Approx. Cost
Muirhead K4426	63 94 125	2 3 6	Multiple speeds Flat bed Automatic send/receive 200 Document loader Roll feed Electrostatic copy	
Telautograph Copyphones III	83 100	1 3	Two speeds Flat bed Automatic receiver/feed 75 Document loader Roll feed System Assurance Electrolytic copy	
Alden 1100	65	100 seconds	Automatic send/receive Electrosensitive copy Compatible with TV systems	$4000
Alden 1800	96 48	1 3	Automatic send/receiver Electrosensitive copy Copies 15" x 5" or 15" x 18" Compatible with TV systems	$5000
Infolink Scanatron	100/100	1/2 3/6	Two speed modes Flat bed Automatic send/receive 50 Document loader Roll feed Electrolytic copy	$1600

Sub-Minute Automated Systems

3M Company Express 9600	96/200	20-35 seconds at 9600 b/s	Flat bed Totally automated Electrostatic copy Data compression by Huffman Coding	
Graphic Sciences DEX 5100	96/200	20-35 seconds at 9600 b/s	Flat bed Totally automated Data compression by Huffman Coding	$12,000 $300/month
Rapidfax 100	67/200 100/200 200/200	35 50 90	Flat bed Automatic send/receive 50 Document loader Roll feed Electrostatic copy Broadcast to 14 receivers	$265-$285/ month

As can be seen in Table 6, most of the machines are quite similar within each category, varying somewhat on the number of selectable speeds and resolutions. Almost all of the units are transceivers, except for the Graphic Sciences 4000 series of transmitters, receivers, and transceivers, and Infolink's Scanatron model, which is a separate transmitter and receiver. There are, however, some units that have unique features. These include the Graphic Sciences Broadcasters, Xerox Telecopier 200, Xerox 400-1 Telecopier and 3M 2346 machines, and the Alden models.

The Broadcasters made by Graphic Sciences are especially designed for multi-point networks. The manual DEX Broadcaster can simultaneously transmit information to ten locations. Automatic machines in the 4000 series become multi-point systems when interfaced to a FAX-900 Broadcaster, which is a push-button unit. The 900 Broadcaster and DEX 4100 are capable of sending copies to 9, 17, or 25 other units simultaneously, depending on the configuration selected.

The Xerox Telecopier 200, shown in Figure 13, is the only machine reviewed that reproduces the documents on ordinary bond paper. A modulated laser provides the light source for xerographic printing. The Telecopier, as an example of a totally automated machine, has self-checking electronic logic to control send and receive operations. The unit automatically answers a phone call, sets the proper transmission speed, and sends or receives information. An automatic dialer has a digital clock that can be set to transmit material at any time. The dialer reads a coded phone number, dials it, and sends the copies to other unattended machines. Messages

Figure 13. Xerox Telecopier 200 Transceiver

can thus be sent and received at any time without operator assistance.

The Xerox Telecopier 400-1 and 3M 2346 are semi-automatic models. The documents are still loaded separately by hand, but the machine automatically "grabs" and ejects each page. In other manual equipment reviewed, the copy must be loaded onto the drum manually by placing one edge of the paper under a metal clamp-bar. The 3M 2346 machine is shown in Figure 14. Like the Xerox 400-1, it is a desktop transceiver. Four different speeds can be selected; other features include automatic margin adjustment, transmission interrupt, and one-line and error signals.

Alden's automatic machines can also be used to make copies of video pictures, computer printouts, and CRT graphics displays.

Figure 14. 3M 2346 Desktop Transceiver

Future Developments

Given the limitations of a narrow bandwidth, will it be possible to increase the performance of visual systems much beyond their present capacities? The answer lies primarily in advancements in electronic technology and the potential application of efficient data compression techniques.

As was seen, the main problems encountered by visual systems are the interrelated factors of picture quality, transmission time, and cost. It is relatively easy to improve the quality of the picture by expanding memory storage capacity. A primary concern, however, is the cost of additional memory chips. It is much more difficult to decrease the transmission time, for this involves complex signal processing operations to reduce the total amount of information without overly affecting image quality.

In order to generally assess the future developments of visual teleconferencing systems, this section takes a quick look at some electronic's products that are applicable to videographic systems. It also suggests some data compression techniques that have potential for graphic and pictorial information.

Some Advancements in Electronic Technology

Electronic technology is rapidly and pervasively changing society. Once considered the tool of only scientists and mathematicians, computers are now a part of everyday life. They regulate a car's engine, provide push-button banking, schedule airplane flights, tally our grocery bills, and entertain us with video games. It is not, therefore, surprising that electronics technology is chiefly responsible for the improvements in visual teleconferencing systems.

For the past 30 years, electronic semiconductor devices have continuously been scaled down to make them faster, denser, and to decrease their power dissipation. Since the late 1960's, the electronics industry has spent tens of millions of dollars on research to develop techniques to further improve their components. The results are dramatic breakthroughs in four areas: dense memory chips, charge-coupled devices, one-chip processors, and fast multiplier chips.

At the heart of most of these devices are large-scale-integrated (LSI) circuits and metal-oxide semiconductors (MOS) which circulate the voltage signals carrying the coded information. It is improvements in manufacturing techniques that is increasing their performance while lowering costs. Not only are established methods more efficient, but five new processes have recently been introduced: H-MOS, V-MOS, D-MOS, SOS, and I^2L. (For descriptions of these processes, see Altman, 1977a, 1977b; Le Boss, 1977; Pashley and others, 1977). These techniques are providing electronic capabilities previously not possible, including powerful one-chip processors and memory chips that hold at least sixteen times more bits of information.

Processors: All integrated circuitry is steadily being miniaturized. Computers are a dramatic example. IBM recently introduced a minicomputer which Time labeled "The Miracle Chip." It is smaller than a fingernail, yet its performance is nearly equivalent to a room-size computer of 25 years ago ("The Age of Miracle Chips," 1978).

IBM is not alone in the marketplace of one-chip processors. Products are probably as varied as their applications, ranging from 4-bit microcontrollers that

can be assigned specific functions to 16-bit microprocessors that match the power of general-purpose minicomputers. There are also lines of microcomputers with different performance capabilities. The cost of these chips ranges from $10 for a simple controller to $1000 for a high-performance microprocessor ("Microprocessors," 1976). Fairchild, for example, recently introduced a 16-bit microprocessor that is reportedly one of the most powerful single-chip processors on the market today. Its price of $750 includes a software package and a memory capacity of 32,786 16-bit words. It can serve as many as 63 peripheral devices ("Fairchild 9440 Starts Going," 1978).

The compactness and performance of the one-chip processors make them applicable to almost any piece of equipment, transforming it into an "intelligent" device that is capable of performing many types of functions. In addition, their cost is well within range of even the spare-time hobbyist. These chips are already being used in some visual teleconferencing systems; they can also be applied to others, such as the slow scan televideo. Processors could, for example, perform many signal processing operations.

Memory Chips: Dense memory chips are another area of digital electronics that is rapidly advancing. Today's memory devices are capable of much greater bit-packing density than products introduced as recently as a year ago. In 1977, for example, memory chips that held 4,C00 or 16,000 bits became established on the market. This year chips with a 65,000-bit capacity were unveiled, and 262,000-bit products are on the horizon. (Altman, 1977; Koppel & Maltz, 1976; Coe & Oldham, 1977; Coker, 1977). Like processors, there are a variety of memory devices to choose from--dynamic or static random access, read only, programmable or erasable read only, charge-coupled, bubble, and magnetic disc memories. The costs of established chips are steadily declining, and the new high-density devices have potentially an even lower cost.

The availability of increasingly dense and faster memory chips that cost less directly affects those systems that use digital memories to store picture information, including the televideo systems and many of the telegraphics models. It appears that the greater bit-packing density and anticipated lower costs would make it feasible to upgrade storage capacity. The televideo systems, for example, use dynamic random access memories (RAM's) that hold 4096 (4K) bits per chip. The price of these chips is now about 15 millicents per bit. However, the potential cost per bit of the 16k chips, which have four times the storage capacity, should be one-half to one-fourth less, or roughly 8 to 4 millicents (Coker, 1977; Coe & Oldham, 1977; Altman, 1977c). In addition, most of the 16k chips are compatible with the 4k's, so can be used in one system. The new 65k chips are even more remarkable. They make it possible to put all of the memory of the Robot slow scan system on one board, where it now has sixteen.

Charge-Coupled Devices: Charge-coupled device (CCD) memories are another possible approach to increasing storage capacity. They offer a higher bit density and potentially lower cost than RAM's, and they are uniquely applicable to analog systems.

CCD memories are capable of storing 10 to 100 times more bits per chip than semiconductor devices, an important consideration in a slow scan or telegraphics system, where increased picture quality requires multiple levels of storage. Memory chips with 9k, 16k, and 65 k capacities have already been marketed, and future designs will contain 128k bits and more. In addition, the potential cost of CCD memory is 3 millicents or less per bit, about one-fifth the cost of a 4k RAM (Altman, 1977, 1977c).

Because a CCD memory is basically analog in nature, it seems to be particularly applicable to audio and video systems. Amelio (1974) suggests that a CCD could be ideal as a time-sampled shift register. It acts as a variable delay line (i.e., the charge packets are shifted through all the elements of the structure over a desired interval of time) that can be clocked to perform buffer functions. For example, a CCD shift register can be loaded whenever the data appear in bursts (as when a video image is grabbed into memory). The data can then be stored for a given interval and read out at the desired rate. This has obvious applications in a scan converter, for the data can be buffered in and out of memory at fast and slow scan rates. It is also possible to combine RAM's and CCD's in a memory design especially suited to a slow scan system (Metgzer, 1975; Altman, 1977d).

The basic analog nature of charge-coupling has wide application in complex signal processing operations needed for data compression, conversion, filtering, modulation, and multiplexing (Amelio, 1974; Altman, 1974; Gundlach, 1977; Mattara, 1977; Zimmerman & Barbe, 1977). It is expected that a variety of CCD products will be marketed in 1978, including analog-digital converters, delay lines, fast multiplier chips for algorithmic transforms, band pass and low pass filters, and modems. Reticon Corporation has already introduced a CCD transversal filter capable of performing the chirp Z algorithm to calculate a 512-point Fourier transform that can be used for data compression.

A charge-coupled device can play another role--it acts as a natural image sensor that determines the precise location of each element in a picture (present scanning equipment is not exact because it is affected by random electrical noise). As Gundlach (1977) and Altman (1977d) state, CCD sensors can be used in facsimile systems, video cameras, and other imaging products.

CCD technology, which was pioneered by Bell Laboratories in 1970, has been extensively researched by the electronics industry (including Fairchild, RCA, IBM, Bell Northern, Texas Instruments, Intel, Signetics, Honeywell and Phillips. It is based on the relatively simple principle that all mobile electric charge stored in a semiconductor storage element (well) can be transformed to an adjacent well by the external manipulation of voltage. The amount of the electrical charge can represent information. Because the amount of stored charge depends on the applied voltages and capacitance of the storage element, the information can be easily manipulated. In signal processing and memory devices, an input signal represented by a charge packet, is introduced by a standard element and then transferred from well to well by pulsing the appropriate electrodes in sequence.

Fast Multiplier Chips: Fast mulitplier chips are paving the way for complex signal operations that previously could only be carried out by using large off-line computers. These new chips can quickly compute autocorrelations and transforms necessary for digital filtering and compression.

Among the many high-speed chips being introduced, two are described by Waser and Peterson (1977) and Mick and Springer (1976). They perform fast multiplications that make it possible to implement complex mathematical calculations. Both devices are considered to have great potential for digital video compression, voice

compression, and facsimile.

Data Compression

Data compression is apparently essential if good quality images are to be transmitted quickly over a voice-grade telephone line. As electronic technology advances it is becoming possible to implement sophisticated compression techniques that reduce the total number of bits transmitted. This can be done by hard-wired logic, processors, or both.

Hard-wired logic refers to integrated circuitry that is able to perform certain operations without the assitance of an external processor. For data compression, the circuitry must be capable of fast multiplications. In the past, multiplication was performed by a series of additions that required large bit words, were slow, and entailed expensive circuitry. The new fast multiplier chips can now perform these functions.

Microprocessors or micro- and minicomputers can also be used for compression operations. Within a matter of nanoseconds, they can calculate sines, cosines and other complex calculations.

The primary objective of data compression is to transmit only enough bits of information to recognizably represent the original message. The total amount of bits is the product of the number of samples taken and the number of bits used to code each sample. For instance, to completely digitize a message with an audio frequency of 3 kHz, a theoretical minimum of 6000 samples per second are needed (the Nyquist rate). In addition, 7 bits may be used to code each sample, resulting in a total of 42,000 bits of information. It would take roughly 20 minutes to transmit this information over an ordinary telephone line. To reduce the total bit content, the number of samples can be decreased and/or a more efficient coding method can be used. Because a message--graphics, picture, or voice--contains redundant information, it can be adequately represented by less bits.

There are many types of data compression techniques; some are still in the theoretical stage, but many are being applied in both experimental and actual situations. Some of these techniques are:

Two-tone images:
- Run length coding
- White block shipping
- Variable length coding
- Predictive differential quantizing

Half-tone images:
- Differential pulse code modulation (PCM)
- Differential PCM with adoptive prediction
- Adaptive differential PCM
- Fast discrete cosine transfer
- Delta modulation
- Adaptive delta modulation
- Two-component code
- Interframe coding
- Interpolative picture coding
- Shift Vector transmission
- Linear predictive coding
- Important points

Descriptions of these methods can be found in "Image Bandwidth Compression" (1977) and in numerous other sources.

All of the techniques attempt to eliminate redundant image content by minimizing the number of bits needed to code the information. In most cases, the coding scheme is designed so that only the changes in picture elements are transmitted. To illustrate this process, simple hypothetical applications of two techniques are briefly described: run length coding to compress two-tone images and differential PCM to compress pictures.

Run Length Coding: Two-tone images, such as graphics and facsimile, can be more easily compressed than pictures, for they contain areas that are either all black or all white. In most cases, only two bits are required to code each sample: black is 1, white is 0. Images that contain complex graphics and typewritten text still require a great number of bits to reproduce the total image content and retain satisfactory resolution. Run length coding reduces the total bits transmitted by coding only the changes from black to white, or the locations of the boundary points. For example, a line of picture elements may contain 10 white elements, followed by 4 black, 15 white, and so forth. Rather than coding each element, only the "run lengths" of 10, 4, and 15 are coded and transmitted.

A simple design that employs this coding method might include an analog-digital converter, an encoder, decoder, and digital-analog converter. After the analog signals representing the original image had been digitized, they would be encoded according to a run length format. All the white elements would be represented by a 0 bit. This would not change until a black element was scanned. The encoder could be a processor or a fast multiplier chip. The compression ratio would depend on the level of redundancy in the image and on the particular statistical code used.

At the receive end, the data would be decoded. If the image had been highly compressed, it is possible to enhance, or artificially reconstruct part of the information by a fast Fourier transform. The transform relates the encoded bit pattern to the frequencies and amplitudes of the original analog signal by performing a series of sinusoidal calculations. A fast multiplier chip or processor could be used for this operation. The data would then be reconverted to analog form for display on a monitor or facsimile reproduction. Because a minimum number of bits would be transmitted to represent the image, it may be necessary to also send an error correcting code. If bits are lost during transmission, the message would then be retransmitted.

Huang (1977) presents a detailed discussion of compression techniques for two-tone images, including run length coding. From his studies, he found that Huffman coding resulted in a 5:1 compression ratio for weather maps. Huffman is one of the most efficient variable-length codes. It uses short code words for frequent messages and long ones for less frequent messages. Huffman coding is used in the new six-minute facsimile machines, such as the 3M Express 9600.

Differential Pulse Code Modulation: Differential pulse code modulation (DPCM) is one of the most widely used methods of picture compression for both narrowband and wideband channels. Like the run length technique, it transmits only changes but the coding method differs. In standard DPCM, a coder predicts the value of the present sample according to information that was previously sent. The difference between the predicted and actual value is then quantized and transmitted. This technique reduces the total number of bits needed to code each sample.

In comparison to black and white images, pictures contain much more information, for they also have gray or color values, and in some cases, animation. It is therefore much more difficult to compress pictures without distorting the quality.

For greater compression, DPCM is often used in combination with other techniques. One method is a fast Fourier transform, which mathematically divides a complex signal into its base frequency and associated harmonics in phase relationship.

In a simple example of picture compression, the original analog signals are first mathematically transformed by a fast Fourier analysis. This transform yields a number of coefficients that represent the base frequency and harmonics. This operation could be performed by a fast multiplier chip, processor, or a type of Fourier filtering device. The frequency coefficients are then coded by a technique such as DPCM to optimize the use of bits. Those coefficients representing less information may be coded by fewer bits, with a greater proportion of bits devoted to the high-content coefficients. Because the high frequencies carry little picture information, many of the coefficients may not be coded at all, compressing the data by perhaps one-half. At the receive end, the signals go through a reverse process; first being decoded and then inversely transformed to convert the frequency coefficients into video signals that can be shown on a monitor. As in the case of run length coding, the Fourier transform can also approximately reconstruct the information that was not transmitted. The efficiency of this compression scheme depends partly on the number of bits needed to code the frequency coefficients and the type of DPCM used.

Differential PCM often results in a 2:1 compression ratio. NEC's color televideo system, for example, cuts the information by half. By combining DPCM with other techniques, the data may be reduced further (Armstrong, 1974; Erikson, 1975). The recent introduction of new DPCM coding and modifications of the Fourier transform may also improve the efficiency of these techniques (Sharma & Netravali, 1977; Zschunke, 1977; Chen & Smith, 1977).

Summary: Run length coding and differential PCM are only two of many techniques that can be used to compress information and decrease transmission time. There are, for example, methods that divide a picture into small blocks for more efficient coding; adaptive sampling rates that conform to the degree of detail in an image and sample more finely in some areas than in others; and techniques that incorporate the psychovisual properties of human vision. As research continues to progress and more coding methods are tested, it is expected that data compression will become increasingly applicable to visual teleconferencing systems. This possibility seems especially promising when one considers the advancements in electronic technology and their pertinence to signal processing operations and the improvement of picture quality.

The growing application of electronic devices to the telecommunications industry and the telephone itself, the trend toward digitizing audio and video information for both narrowband and wideband channels, and the amount of research on data compression all point to future improvements in telewriting, televideo, and facsimile systems.

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